Using Architecture Analysis for Mission Capability Acquisition

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Abstract

Historically, the DoD Architecture Framework has been used for designing new systems. Recently though, architectural work that was developed for Fleet Battle Experiment India (FBE I) was used to define the framework for the Mission Capability Package (MCP) for Naval Time Critical Targeting (TCT). The architecture products were used to describe, assess and choose investment strategies leading to a more capable and efficient integration of systems that would produce the desired mission capability. The resulting analysis provided insights for improving the networking of sensors C^2 and weapons systems. Additionally, the architecture methods also provided insights on particular areas of the architecture where there might be system duplications and gaps in executing the activities required by the operators.

This paper summarizes an architectural methodology that can be used to enable a capabilities based approach to the planning and acquisition of DOD families of systems (FoS) that must interoperate with each other in the conduct of military operations. While individual systems within the FoS can have substantial mission capabilities, it is the collective capability of the FoS operating synergistically that is the objective of the FoS systems engineering process. This requires that mission capabilities are traceable to systems interoperability in order for designers and planners to choose the correct FoS. Systems that operate synergistically to achieve (collective) mission capabilities must be aligned in program planning, acquisition, certification, and deployment. This paper focuses on FoS systems engineering aspects of planning and acquisition and shows how the architectural products developed for experimentation were used in both FBE I and the Naval TCT MCP.

Introduction

Over the past year the Assistant Secretary of the Navy for Research, Development and Acquisition Chief Engineer of the Navy (ASN (RDA) CHENG) under the direction of RADM Mathis conducted a rigorous analysis of Time Critical Targeting (TCT) using architectural methods. Dr. Dickerson, the Director of Architectures for the ASN (RDA) CHENG and CAPT (USN Ret) Soules, Principal from Booz Allen and Hamilton, led a government and contractor team that used the Naval Warfare Development Center (NWDC) Fleet Battle Experiment India (FBE I) to assess new architectural methods for analysis. This effort evaluated the TCT portion of the FBE I experiment which focussed on how C2 Doctrine changes combined with new networks could possibly lead to an implementation of Network Centric Warfare. The architecture products used were in compliance with the DOD Architecture Framework Document 2.0 but were used in a unique fashion to attempt to assess the TCT architecture to assist in making acquisition decisions for the Naval POM 04 TCT Mission Capability Package (MCP).

CNO N70 and ASN (RDA) CHENG have used these architecture products in conjunction with other engineering and programmatic products to support the development of the Naval TCT Mission Capability Package (MCP). CNO N70 is responsible for the development and integration of the Mission Capability Packages. ASN (RDA) CHENG is the senior Naval technical authority for the overall architecture, integration, and interoperability of Combat, Weapons, and Command, Control, Communications, Computer and Intelligence (C^4I) Systems.

An Architectural Methodology

Because collective mission capabilities derive from the inter-relations and dependencies between the systems, the complexity of the description of the FoS increases rapidly as we proceed from high level concepts to their instantiation by physical systems. The architectural methodology is part of a systems engineering discipline that documents

"the structure of components, their relationships, and 'the principles and guidelines governing their design and evolution over time".[1]

The architecture is the first level of design that can be reasoned about. It provides the framework for engineering development as well as for the operational uses of the FoS. It also provides the basis for the transformation of FoS planning and acquisition into a capabilities based strategy.

The Framework Architecture products can be organized into five groups, or use cases for the products that support FoS systems engineering and acquisition:

- Operational Concept
- System Functional Mapping
- System Interface Mapping

[1] IEE Standard 610.12 as adapted by the DOD Architecture Framework 2.0

- Architecture Performance and Behavior
- Acquisition Strategy

In figure 1, these groups are generally ordered (top to bottom) by the level of complexity anticipated for their use. How architectures provide the framework for FoS systems engineering and acquisition is the subject of the remainder of this section.

The first four of the five groups of products can be generally associated with the four steps of classical systems engineering:

- Requirements Analysis
- Functional Analysis
- Synthesis
- Design Verification

While FoS systems engineering must follow the principles of classical systems engineering, the complexity of the FoS and the preponderance of legacy systems in the FoS will limit in practice the system engineer's ability to apply these principles. Requirements analysis and the functional design of the FoS to achieve specific capabilities can be a manageable task. These become stable views of the FoS that are much simpler to understand than the underlying and constantly changing physical architecture. Synthesis then becomes a mapping of the legacy systems in the FoS into the functional view of the architecture and a determination of how to use the remaining trade space for new systems and system improvements. Design verification for the FoS is reduced in complexity by focusing on threads of systems that provide the supporting functionality for specific mission capabilities.

Operational Concept

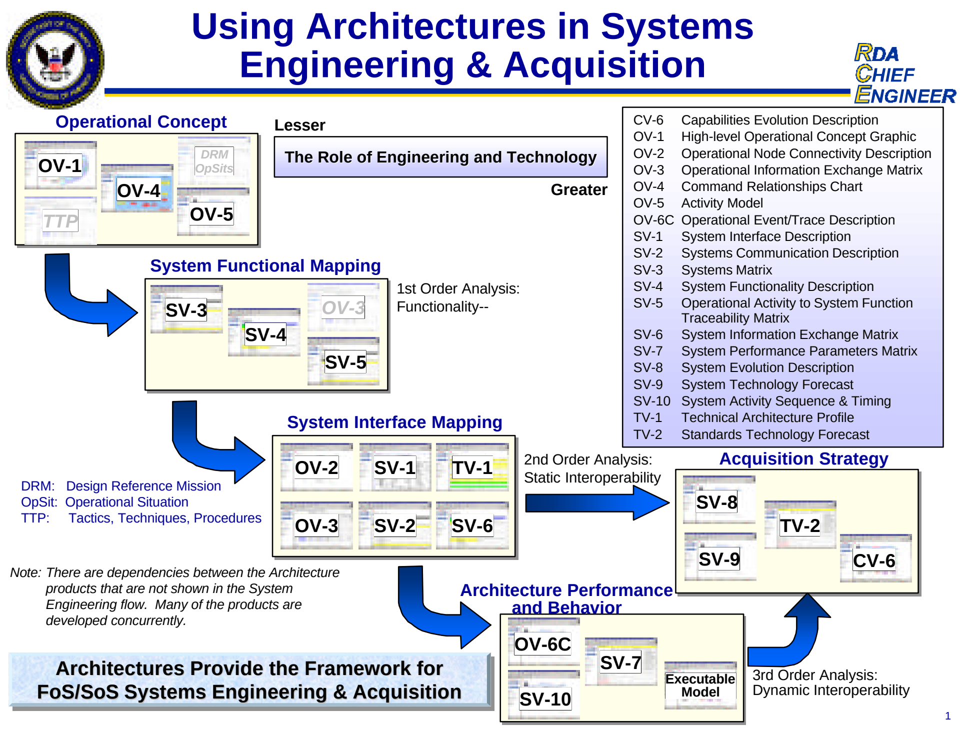
The operational concept should be a high level abstraction of the problem to be solved and the proposed approach to solve the problem. It can also include boundary conditions and invariants (i.e., things not in the trade space of the solution). Three Architecture Framework products can be used to support description of the operational concept:

- OV-1: High Level Operational Concept Graphic
- OV-5: Activity Model
- OV-4: Command Relationships Chart

These products lay the foundation for systems development and facilitate communication by providing context, orientation, and focus. They also serve as the entry point for requirements flow down into the architecture.

<u>OV-1 (High Level Operational Concept Graphic)</u> This view should provide a high level description of what the military force is and its intended effects on the defined threat. It should also establish the boundaries of the battlespace and the uses of the military force to achieve effects. For the purpose of this initial work, we defined a mission capability as the possession of the means to use military force to achieve an

intended effect within the battlespace. It is also reasonable to use the OV-1 to describe an evolution of capability increments that lead to full capability. Uses of the OV-1 for systems engineering must also be tied to a Design Reference Mission (DRM), Operational Situations (OpSits) and Tactics, Techniques and Procedures (TTP). These are indicated as faded boxes in figure 1.



Using Architectures in FoS/SoS Systems Engineering and Acquisition
Figure 1

OV-5 (Activity Model) This view should provide the first descriptions of how the military force will achieve its intended effects. Each use of military force (from the OV-1) must be enabled by one or more operational activities. These activities, along with the input or output of data and services between them, form the activity model (e.g., an IDEF-0). However, no order of execution or timing relations need be established at this point. A paradigm of five high level activities can be used to organize most operational activities: monitor, assess, plan, execute, sustain. The execution activity can take on different meanings. In combat systems it can mean either combat direction (e.g., C^2) or engagement (e.g., weapons delivery).

OV-4 (Command Relationships Chart) This view documents the control relations over the operational activities, establishing by what authority or mechanisms activities are directed to execute or remain idle. It is the basis for C^2 relations in the architecture.

System Functional Mapping

Due to the complexity of the FoSs of interest, simply bookkeeping the data describing the systems, their relationships, and evolution is an overwhelming task. The functional view of the solution provides a stable model which is easier to manage and against which the FOS can be mapped. Three Architecture Framework products support the system functional mapping:

- SV-4: System Functionality Description
- SV-5: Operational Activity to System Function Traceability Matrix
- SV-3: Systems Matrix

Together, these products provide the linkage and traceability of capabilities and requirements flowdown between the operational and the physical views. The functional view is also the first level of the architecture that is appropriate for systems assessments. The products provide the basis to answer the question: *Does the FoS system architecture provide the functionality to support the desired mission capabilities?*

Assessments using this functional group of products provide the basis for a first order analysis of combinations of systems proposed to comprise the FoS. In the systems engineering process, our attention will be on an FoS that is intended to solve the problems laid out in the OV-1. For example: an analysis of gaps and duplications reduce the size of the system trade space. The result of the first order architecture analysis is the starting point for systems engineering analysis.

SV-4 (System Functionality Description. This Architecture Framework product is more useful for FoS system engineering when it is broken into three views that would revise the Framework:

SV-4a: List of Systems Functions

SV-4b: System Functional View (SFV)

SV-4c: Logical Interface View (LIV)

The SV-4a is the list of system functions that will be used to enable or execute the operational activities.

SV-5 (Operational Activity to System Function Traceability Matrix) This is a matrix that summarizes which individual system functions are used to enable or execute which individual operational activities. Each cell in the matrix points to a use case of the system functions. Using the system functions, the SV-5 provides the traceability of operational capabilities into the FoS.

SV-4b (System Functional View) The SFV is derived from the OV-5 using the SV-5. It is the functional analog of the activities model and shows the relationships and dependencies amongst the system functions.

SV-4c (Logical Interface View) The LIV uses the OV-5 input/output relations to build the logical interfaces between the related functions in the SFV. This view can be represented as an overlay to the SFV or as a hyperlinked drill down on the connections between the functions.

SV-3 (Systems Matrix) This Architecture Framework product is more useful for FoS systems engineering when it is broken into three views that would revise the Framework:

SV-3a: Systems to Functions Matrix

SV-3b: Operational Activity to System Traceability Matrix

SV-3c: Systems Matrix

The SV-3a is a matrix that summarizes which individual physical systems are used to enable which individual system functions. Each cell of the matrix points to a functional use case of the physical systems. Using the systems functions and the SV-5, the SV-3a provides the direct traceability of operational capabilities into the physical systems of the FoS. This results in a matrix, (the SV-3b), that is analogous to the SV-5 but at the physical level. Each cell of the SV-3b matrix points to an operational use case of the physical systems. The SV-3c is in the form the Systems^2 matrix of the Framework, but in this methodology is built using the relations between system functions provided by SV-4b (SFV). The logical interfaces of the SV-4c taken with the SV-3c can be used to begin building a physical instantiation of the OV-3, which is indicated in figure 1 as a faded box.

System Interface Mapping

The system interface mapping builds all views of the connectivity between the systems in the FoS: operational, system, and technical. Six Architecture Framework products can be used to support the system interface mapping:

- OV-2: Operational Node Connectivity Description
- SV-1: System Interface Description
- TV-1: Technical Architecture Profile
- OV-3: Operational Information Exchange Matrix
- SV-2: Systems Communication Description
- SV-6: System Information Exchange Matrix

From the point of view of systems engineering trades, these views provide the basis to answer the question: *Have the appropriate standards been applied and the levels of interoperability been properly aligned so that the individual systems in the FoS can be expected to interoperate with each other successfully to enable the functionality sought for the FoS?*

OV-2 (Operational Node Connectivity Description) The operational nodes in this view are meaningful groupings of the activities in the OV-5 (Operational Activity Model). These nodes are associated with physical or organizational nodes in other views of the architecture. They can be thought of as task-oriented cells where work is accomplished. Because the activities of the OV-5 carry input and output relations, the nodes of the OV-2 inherit these relations, which are usually referred to as need lines. From a systems engineering point of view, the nodes in the OV-2 should be created to establish natural lines of communication between physical locations. When the architecture is physically instantiated, communication occurs between operational nodes, vice between activities. However, need lines are not the communications paths. (The communications paths are described in the SV-2).

SV-1 (System Interface Description) This view links the operational and system views of the architecture. The SV-3b (Operational Activity to System Traceability Matrix) provides the linkage. At the highest level, the SV-1 organizes the systems along the paradigm of monitor, assess, plan, execute, sustain (possibly with the C^2 aspect of execution, i.e. combat direction, being separated from the engagement aspect of execution, e.g. weapons delivery). This representation relates to the OV-1 and is useful for high level planning. At the systems engineering level, the SV-1 is a mapping of systems to the OV-2 using the SV-3b. The associated operational and system need lines are in concordance because of their common derivation through the SV-5.

TV-1 (Technical Architecture Profile) The Architecture Framework represents the technical component of the architecture as the set of rules that govern system implementation and operation. In this sense, the TV-1 should go beyond interface standards and protocols. In practice, the TV-1 is frequently seen as only the list of standards and protocols associated with the transport layer of interfacing and communications between systems. However, in the Framework 2.0 the notional example of the TV-1 addresses service areas, services, and standards that go beyond interfaces. Therefore, it may be appropriate to decompose the TV-1 into interface standards that align to an overarching accepted standard like OSI and into other standards related to services and physical systems.

OV-3 (Operational Information Exchange Matrix) This Architecture Framework product can be adapted to our FoS system engineering process by deriving it from the operational and system architecture products already developed. The Architecture Framework defines the Information Exchange Requirements (IERs) of the OV-3 view as the relationship across the three basic entities of the operational view of the architecture (activities, operational nodes, and information flow) as a focus on the specific aspects of information flow, namely *who* exchanges *what* information with *whom, why* the information is necessary, and in *what manner*. The OV-3 was intended to emphasize the logical and operational characteristics of the information. However, the fundamental operational information exchanges are really identified at the activity level in the OV-5 via the input and output relations. With our adaptation of the OV-2 as meaningful groupings of activities (cells where work is done) to establish communication need lines, the OV-2 becomes the more natural starting point for building the OV-3. If the non-

physical standards and protocols from the TV-1 are applied to these need lines, then a systematic and well organized operational view of information exchange is accomplished and a foundation for the System Information Exchange Matrix is established.

SV-2 (Systems Communication Description) This view represents the specific communications systems pathways or networks and the details of their configurations through which the physical nodes and systems interface. This product focuses on the physical aspect of the information need lines represented in the OV-2 (Operational Node Connectivity Description). It describes all pertinent communications aspects of the FoS, showing the details of need lines between the systems identified by the SV-1 (System Interface Description).

SV-6 (System Information Exchange Matrix) This Architecture Framework product is made more useful for FoS system engineering by expanding it into a broader view that would revise the Framework. This expanded SV-6 would retain the attributes of the existing Framework product, which is defined as the information exchanges within a node, and from those systems to systems at other nodes. It is easily derived from the OV-3, TV-1, SV-3b and the SV-3c. This makes the SV-6 the system analog to the OV-3. The stronger SV-6 product can be derived because the matrices of the preceding architecture products can be used to create end-to-end views of system information and service exchanges. Each communication and service between two systems can trace the capabilities, activities, functionality, logical and technical interfaces of the architecture.

Architecture Performance and Behavior

The system functional mapping and the system interface mapping provide key insights into the functionality and connectivity of the architecture with traceability to operational capability. As such, these *uses* of Framework Architecture products provide an early validation of the architecture and serve to answer the question: *What can the architecture enable the FoS to actually do?* However, the architecture is not (abstractly) validated until it can be executed as a flow of events, which is accomplished through the products of performance and behavior. The group of architecture products proposed for the use case of performance and behavior can serve to answer the questions: *how well does the architecture perform (to deliver mission capabilities) and does it behave in ways acceptable to the users?* Three Architecture Framework products support this use case and one new product must be added:

- OV-6c: Operational Event/Trace Description
- SV-10: System Activity Sequence & Timing Description
- SV-7: System Performance Parameters Matrix
- Executable Model (new product)

These products are necessary to support system selection decisions, which reside in the domain of FoS systems engineering trade studies (i.e., performance and capabilities vs. cost and risk). However, these products are the most labor intensive of the five groups (use cases) to generate.

OV-6c (Operational Event/Trace Description) This view, which is sometimes called a sequence diagram, is the most basic product which addresses the executability (or dynamic validity) of the operational view of the architecture. It enables the traceability of actions in a scenario or critical sequence of events. The OV-6c organizes the OV-5 activities around the OV-2, using the OV-4 for control (or triggering) of architecture responses to scenario events. It introduces timing and sequencing into the activity model (OV-5). Insights into dynamic validity, throughput, and node loading are gained. However, it does not address architecture performance. The performance of the architecture is determined by the performance of the systems and personnel that enable or execute the operational activities.

SV-10 (System Activity Sequence & Timing Diagram) This view should be inherited from the OV-6 using the mapping of the SV-5 and other SV-3,4 products. The Architecture Framework calls out three systems models that are needed to accomplish the complete description:

- SV-10a: Systems Rules Model
- SV-10b: Systems State Transition Description
- SV-10c: Systems Event/Trace Description

There is another view that has proven very useful in architecture assessments. This proposed view would be a fourth product that logically should proceed from the three standard SV-10 Framework Products and is what is labeled an SV-10d.

SV-10d: (Systems to Operational Sequence Mapping) This view is a simple mapping of the SV-3b to the OV-6c. The result is an OV-6c with physical systems associated with the activity flow of the OV-6c. Military operators find this very useful. Derivation of this view through the SV-3b adds engineering discipline to the association of physical systems and operational activities. Still though, architecture performance is not observable until the performance metrics of the individual systems are determined, which is the purpose of the SV-7.

SV-7 (System Performance Parameters Matrix) This view builds on the System Element Interface Description (SV-1) to depict the current performance characteristics of each system, and the expected or required performance characteristics at specified times in the future. The expected characteristics relate to the System Evolution Description (SV-8), whereas the performance requirements for physical systems are traceable only when an allocated baseline has been established (i.e., functions and requirements have been allocated to physical systems). Building the allocated baseline requires the collaboration of multiple stakeholders and is in the domain of FoS systems engineering trades that occur during synthesis.

Executable Model Execution of the architecture is required for both validation and analysis. A number of popular tools are available. RDA CHENG currently has been using a popular tool developed for structured analysis. However, future work will move towards object orientation using the Universal Modeling Language (UML). This will

allow for better re-use of the architecture products and provide better control of attributes through the inheritance properties of UML. The organization, description, and uses of the Architecture Framework products in this paper have been written with extensibility to UML in mind, while preserving the structured analysis attributes of classical systems engineering.

Acquisition Strategy

A capabilities based acquisition strategy aligns the evolution of systems, technologies, and standards into an acquisition strategy to support the evolving capabilities needed for the FoS. Three Architecture Framework products, and a new proposed product, are needed to support the description of the acquisition strategy:

- SV-9: System Technology Forecast
- TV-2: Standards Technology Forecast
- SV-8: System Evolution Description
- CV-6: Capability Evolution Description

Together, these products provide a description of the evolution and acquisition of the system improvements to the FoS that is traceable to mission capabilities.

SV-9 (System Technology Forecast) A system Technology Forecast is a detailed description of emerging technologies and specific hardware and software products. It contains predictions about the availability of emerging capabilities and about industry trends in specific timeframes (e.g., 6-month, 12-month, 18-month intervals), and confidence factors for the predictions. The forecast includes potential technology impacts on current architectures, and thus influences the development of transition and objective architectures. The forecast should be tailored to focus on technology areas that are related to the purpose for which a given architecture is being build, and should identify issues that will affect the architecture.

TV-2 (Standards Technology Forecast) A Standards Technology Forecast is a detailed description of emerging technology standards relevant to the systems and business processes covered by the architecture. It contains predictions about the availability of emerging standards and the likely obsolescence of existing standards in specific timeframes (e.g., 6-month, 12-month, 18-month intervals), and confidence factors for the predictions. It also contains matching predictions for market acceptance of each standard and an overall risk assessment associated with using the standard. The forecast includes potential standards impacts on current architectures, and thus influences the development of transition and objective architectures. The forecast should be tailored to focus on technology areas that are related to the purpose for which a given architecture description is being built, and should identify issues that will affect the architecture.

SV-8 System Evolution Description) The System Evolution Description describes plans for "modernizing" a system of suite of systems over time. Such efforts typically involve the characteristics of *evolution* (spreading in scope while increasing functionality and flexibility), or *migration* (incrementally creating a more streamlined, efficient, smaller and cheaper suite), and will often combine the two thrusts. This

product builds on the previous diagrams and analyses in that information requirements, performance parameters, and technology forecasts must be accommodated.

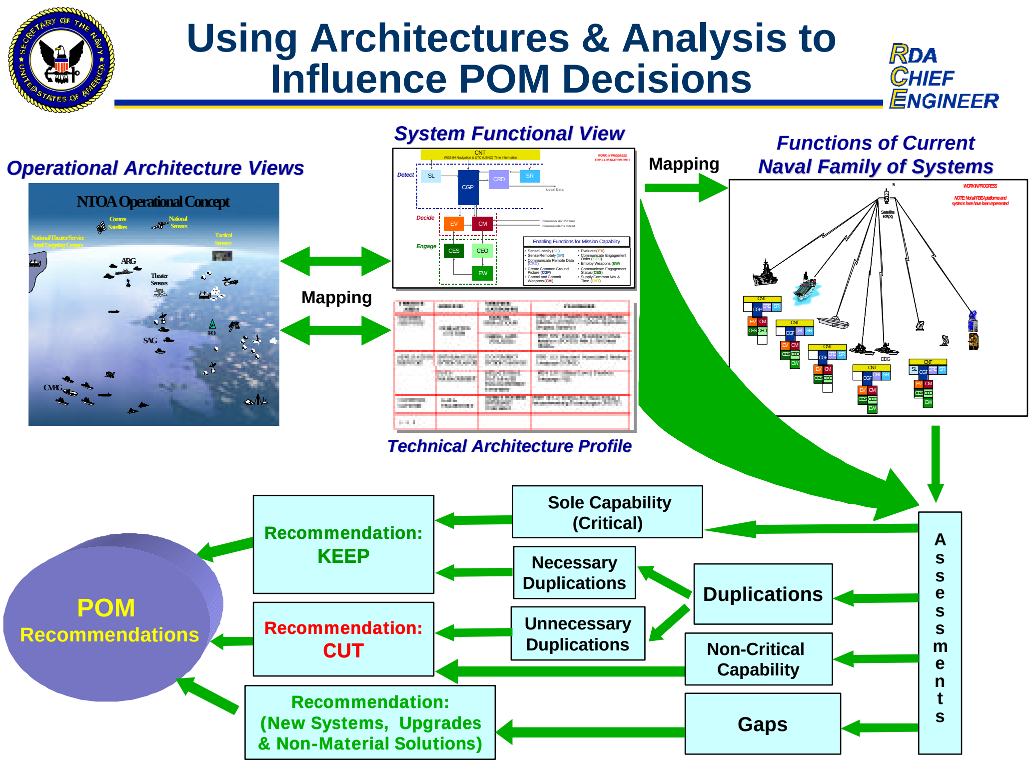
In FoS systems engineering, the Systems Evolution Description will draw heavily not only from the System Technology Forecast (SV-9) but also from the Standards Technology Forecast (TV-2). This is because the FoS derives its capabilities through the interoperation of systems, not just through the operation of individual systems. Thus, the evolution of system connectivity must be given equal attention with individual system evolution.

CV-6 (Capability Evolution Description) This new view has been proposed and considered by various elements of the DOD. This view would be a high level graphic for managers and executives to use for oversight of FoS alignment during acquisition. Portfolios of programs would be bundled by the capability increments referred to in the Operational Concept (OV-1). Increments of capability introduced over time would then establish the evolution of the FoS in acquisition. The delivery of systems and the associated integration and interoperability strategy would be aligned and displayed in the CV-6 graphic, so that connectivity, alignment, and traceability to capabilities are all displayed in one graphic.

Applying The Architectural Methodology

During the course of the past two years the Director of Architectures for the Chief Engineer of the Navy office conducted a pilot program in conjunction with the Naval Warfare Development Center to assist in analyzing a Fleet Battle Experiment. Using the methodology described in the previous pages the Director of Architectures documented the design and execution of the Time Critical Targeting portion of the experiment using the views and products discussed in the methodology in the previous section.

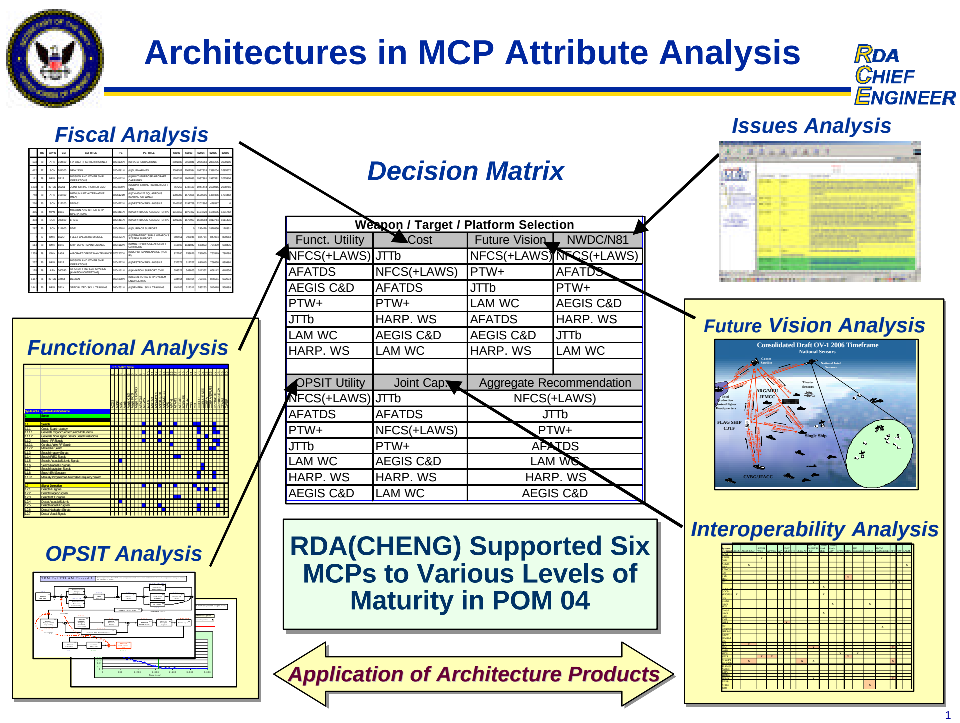
The FBE I views were then compared and integrated with other architecture products derived from other Time Critical Targeting efforts ongoing in the Navy. The results from the integrated architectures were then presented to OpNav N70 (Integrated Warfighter Requirements) for consideration in making POM 04 acquisition decisions in support of the Time Critical Targeting Mission Capability Package.



Using Architectures & Analysis to Influence POM Decisions
Figure 2

The FBE I pilot proved to be successful. The products were documented and stored in the Joint Mission Area Analysis Tool (JMAAT) that in turn provided a standard and disciplined approach to capturing the operational, systems and technical views. Figure 2 illustrates the first order assessments of FoS system functionality that were used to make decisions in the POM 04 build. In addition key integration solutions were identified which influenced priorities and decisions for investments that could make a difference in mission capability. As a result of the pilot the ASN RDA CHENG was able to begin to institutionalize the process across the Navy to begin to address other mission capability packages and develop a common language between the organizations that support them.

The RDA CHENG support of the N70 POM04 build was used in six of the N70 MCPs to various levels. Six attributes of each MCP were identified to support MCP decisions, as illustrated in Figure 3. Analysis of four of the six attributes were supported by architectures products as depicted in Figure 3, including Functional Analysis, OpSit Analysis, Interoperability Analysis, and Future Vision Analysis.



Architectures in MCP Attribute Analysis
Figure 3

. The architectural methods proposed in this paper are providing a means for operators, engineers and acquisition specialists to implement mission capabilities through a common language and approach. By evaluating system integration and interoperability as well as the impacts on doctrine, training, maintenance and logistics through out the concept development, engineering and acquisition process, the ability to acquire fully integrated mission capable Family of Systems can begin to become a reality